IN SITU SEDIMENT TREATMENT TO CONTROL ODOURS AND ENHANCE BIOLOGICAL BREAKDOWN OF ORGANIC MATTER IN SHING MUN RIVER, THE HONG KONG SPECIAL ADMINISTRATION REGION

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ABSTRACT

The Shing Mun River (SMR) in Hong Kong runs through Sha Tin in the New Territories and is a major storm drainage system, recreational and aesthetic amenity. The SMR previously received significant amounts of domestic sewage and industrial effluents from within the watershed that increased the sediments' organic content. The sediments are very reduced and have high concentrations of sulphides. During low tides when the sediments are exposed there are significant odour problem that cause the residents to complain to the government. In response to the complaints the government undertook a bioremediation program that involved calcium nitrate addition directly into the sediments. This treatment increased the mean sediment oxidation-reduction potential from –330 mV to +76 mV and decreased the mean sediment sulphide concentration from 2,125 mg/kg to < 5 mg/kg. Untreated sediments were black and odorous and the treated sediments were light brown and non-odorous.

RÉSUMÉ

A Hong Kong, la rivière Shing Mun (RSM) traverse Sha Tin dans les Nouveaux Territoires et est à la fois: un important système d'écoulement des eaux pluviales, une zone de loisirs et d'agrément. Auparavant, la RSM recevait une quantité importante d'eaux usées d'origine domestique ou industrielle venant du bassin versant, qui augmentait la teneur en sédiments organiques (très réduits et de concentration élevée en sulfure). A marée basse, les sédiments découverts généraient d'importants problèmes d'odeurs qui suscitaient des plaintes des résidents auprès du gouvernement. En conséquence, ce dernier entreprit un programme de traitement biologique consistant à ajouter du nitrate de calcium dans les sédiments. Ce processus augmenta le potentiel d'oxydo-réduction moyen des sédiments de -330mV à +76mV, diminuant ainsi la concentration moyenne des sédiments sulfurés de 2,125 mg/kg à <5 mg/kg. Les sédiments non-traités étaient noirs et odorants, alors que ceux traités étaient marron clair et non-odorants

1. INTRODUCTION

The Shing Mun River (SMR) is contaminated mainly from organic pollutants [primarily biochemical oxygen demand (BOD) loading from agricultural (pig) and human wastes to the river] which has resulted in odour problems, a paucity of biota, poor water quality and a generally degraded environment. The Hong Kong Special Administrative Region Government commissioned a study in 1996 to examine methods of improving the aesthetics (odour and visual) and environmental conditions of the SMR. The previous study found that a strategy combining bioremediation of the sediments and/or selected dredging and some minor engineering works would improve both the aesthetics and the environmental conditions in the river. This paper presents the results of the in situ application of calcium nitrate as an innovative and cost-effective treatment to control odours in sediments.

1.2 Background of the Problem

The SMR was originally a natural drainage river that has been engineered (concrete sides and partial concrete on the bottom) to increase drainage capacity. The river is approximately 5.5 km long and 220 m wide. The organic content in the sediments and the odour problem at the SMR are the two main targets of the bioremediation works. These two problems are inter-related and can be considered in unison. The organic matter can essentially be considered as the "cause" of the odour problem, while the odour issue can be considered as the 'consequence'. It is the 'decomposition' of the organic matter that causes the odour problem. Adjusting the decomposition process can address the current odour problem by converting the odour-causing sulphides to sulphates and also reduce future odour problems by decreasing the amount of organics in the sediment and adding oxidants to the sediments that can be used over time by the bacteria.

Due to the high temperatures (up to 30^{o}C) dissolved oxygen (DO) saturation is low. The low DO coupled with the shallow nature of the river (usually less than 3.0 m) and the large oxygen demand by the sediments limits oxygen transfer to the sediments. The absence of oxygen in the sediments results in the bacteria present using an alternate electron acceptor (oxidant) to biodegrade the organic material. The only readily available oxidant is sulphate that is abundant in seawater and conversion to sulphide is the root cause of the odour problem.

The preferred biodegradation pathway of organic matter, with oxygen as the electron acceptor, is shown in

Equation 1; the present anaerobic pathway, with sulphate as the electron acceptor is summarised in Equation 2:

$$C + O_2 \rightarrow CO_2 + H_2O \quad [1]$$

$$C + SO_4 \rightarrow CO_2 + H_2S \quad [2]$$

From Equation 2 it can be seen that sulphide is produced during the degradation pathway. It is this sulphide production that causes the odour problem in SMR

Odour control can be achieved by supplying an alternate electron acceptor (i.e., oxidant) to the bacteria. The preferred oxidant is oxygen; however, as mentioned previously it has limited solubility in SMR water. The next preferred oxidant is nitrate which is extremely soluble in seawater and is only slightly less energy efficient than oxygen.

Nitrate addition to sediments facilitates two important processes: 1) sulphide oxidation (Equation 3) and 2) increases bacterial degradation rate of organic matter (Equation 4).

$$S^{-} + Ca(NO_3)_2 \rightarrow CaSO_4 + N_2 \quad [3]$$

$$C + NO_3 \rightarrow CO_2 + N_2 \quad [4]$$

Thus, the goals of the project were to:

- remove the existing sulphide odours (Equation 3);
- prevent future sulphide production (Equation 2);
- increase organic degradation rates (Equation 4).

2. METHODOLOGY

Prior to beginning the nitrate addition the treatment areas were sampled for chemical and physical characteristics and are presented in Table 1. The depth of contamination was generally only 50 cm deep and only one hectare area had contaminated sediments 1.0 m deep. Sediment samples were collected with a plastic corer and the section from 10 to 30 cm was sub-sampled and measurements were made on this core slice. Results of the initial sediment characterization are presented in Table 1.

Table 1. Initial Sediment Characterization.

	MEAN	MINIMUM	MAXIMUM
REDOX (mV)	-330	-390	-260
AVS (mg/kg)	2,125	450	4,200
TOC (%)	2.5	1.2	4.2

AVS and TOC values given are on a dry weight basis.

To be judged successful the contractor had to decrease the AVS concentration by 85% and increase the redox to -200 mV. Also; there had to be a total of 30% of the added amendment remaining in the sediments at the completion of the works. The required AVS reduction was based on previous experience with pilot-scale testing in Hong Kong (Babin *et al.* 1998) and was set to produce a significant reduction in odour. The required redox increase was based on the bacterial degradation pathway; when redox is less than -200 mV sulphate reduction is the biological pathway being followed; above -200 mV either nitrate reduction or oxygen respiration are the pathways being followed. The required 30% residual amendment was set as a method of ensuring complete removal of the existing sulphides and providing long-term suppression of further sulphide production.

A total of 18.5 hectares, divided into 25 different sections, in the SMR was identified as requiring bioremediation. Previous laboratory and pilot-scale testing in Hong Kong (Babin et al. 1998) found that calcium nitrate could achieve the required results. A local contractor was selected to undertake the nitrate addition using equipment developed and patented by Environment Canada. The equipment consisted of the patented 8 m wide injection boom, pumping system with flow and pressure controls and the below deck storage tanks.

The treatment was applied to the sediments in two dosages at a 7:3 ratio of the total dosage. Nitrate was injected into the sediments approximately 10-15 cm below the surface of the sediments from a barge equipped with a Global Positioning System (± 1m accuracy) and a winching system was used for propulsion.

Each section to be treated was subjected to 3-4 passes with the 8 m wide boom to ensure complete coverage of the area.

3. RESULTS

The treatment was completed in less than a year. All of the sites treated met the objectives listed in Section 2. Sediment monitoring results post-treatment are presented in Tables 2 to 4.

Table 2. Post Treatment Redox Measurements.

	Post-Application 1	Post-Application 2
Mean (mV)	-3	73
Maximum (mV)	73	145
Minimum (mV)	-101	-12

Table 3. Post Treatment AVS Measurements.

	Post-Application 1	Post-Application 2
Mean (mg/kg)	11	<5
Maximum (mg/kg)	78	7
Minimum (mg/kg	<5	<5

Table 4. Post Treatment TOC Measurements.

	Post-Application 1	Post-Application 2
Mean (%)	2.5	2.3
Maximum (%)	4.1	4.9
Minimum (%	1.2	1.1

4. DISCUSSION

The sediment treatment was successful in meeting all of the performance criteria. AVS was reduced by over 95% (required reduction of 85%), redox increased to well above the -200 mV requirement and the amount of calcium nitrate remaining in the sediments after the last treatment was 51.8% (required residual was 30%).

With respect to the issue of increased degradation of the organic material and concomitant decrease in TOC the results obtained show no significant decrease in TOC concentration. This is not surprising since the overall TOC concentration was relatively low (mean of 2.5% and a maximum of 4.2% pre-treatment) and the relatively short time period involved (less than a year) between the beginning of the treatment period and the final sampling. There is also continued input of organic material which would increase the TOC level in the sediments. However, based on previous work (*e.g.* Murphy *et al.* 1999) testing , the improved environment (more energy efficient oxidant) should have increased the bacterial activity and caused TOC to decrease. Alternately one can assume that the treatment was successful in that, despite continued inputs the TOC did not increase.

There were a few issues discovered during the course of the works that required changes in treatment or changes in monitoring and assessment of results. These are discussed below.

Shallow water. In some areas the water was too shallow for the equipment to move and a smaller, portable unit with less draft was constructed. This unit used a 4 m wide boom and was half the size of the larger unit.

Sediment resuspension. In some areas of the river boat traffic was found to disturb the treated sediments. This could potentially lead to nitrate release into the water column. Although nitrate release was not detected precautions were taken to advise boaters to stay clear of the treated areas which were marked with flags.

Armour Stones. A large swath, approximately 20 m wide, down the middle of the river had large armour stones on the sediments. These stones were place there as protection for two buried pipelines. These areas had very shallow sediments and could not be treated.

Garbage and debris. A significant amount of cables and debris on the river bottom was encountered. This material initially caused a problem by becoming tangled up in the injection boom. This problem was resolved by pre-clearing the treatment area with a rake and removing the debris.

In summary, the treatment was a success and the goals of the bioremediation project were met. Despite some minor technical problems with implementing the work all obstacles were overcome. The treated sediments were light brown and odourless while the untreated sediments were black and had a rotten-egg smell characteristic of sulphides.

A long-term monitoring program needs to be designed and implemented to determine the longevity of the treatment and to plan for future treatments.

The technology has proven effective in treating aesthetic problems in rivers in Hong Kong. Future treatments of other rivers are being considered as a reliable method of improving the environment in Hong Kong.

6. REFERENCES

Babin, J., T.P. Murphy, and J.T. Lynn. 1998. In situ sediment treatment in Kai Tak Nullah to control odours and methane production. Environmental Hydraulics; Proceedings of the seventh international symposium on River Sedimentation, Hong Kong.

Environmental Protection Division, Government of Hong Kong. 1997. Agreement No. CE 19/96. Environmental Improvement of Shing Mun River Main Channel and Associated Nullahs

Murphy, T.P., A. Lawson, M. Kumagai, and J. Babin. 1999. Review of emerging issues in sediment treatment. Aquatic Ecosystem health and Managerment (2), Elsevier Science Ltd. and AEHMS.